The Importance of Materials Science to Ireland

AMBER
Advancing Materials for Impact

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AMBER Executive Summary

Advanced materials are synthetic or highly modified natural materials which have been designed or engineered to have a specific functionality and meet an application need. They have driven technological and societal progress since the stone age and are the basis of modern technologies including semiconductors, renewable energy, automotive, pharmaceuticals, med-tech, construction and food production. As such they are a primary driver of economic growth and industrial competitiveness. However, the materials market faces significant change in the next few decades resulting in an increased focus on innovation and accelerated technology translation at a global scale. **Economic, geopolitical, and societal factors such as population growth and the mass adoption of digital and green technologies are driving an unprecedented demand for materials with the OECD forecasting an approximate twofold increase in the global demand for raw materials from 89 Giga Tonnes (Gt) in 2017 to 167 Giga Tonnes (Gt) in 2060[1].** This is driving increased global competition for finite resources resulting in significant challenges in terms of supply chain vulnerabilities and the consequential impacts on the environment and sustainability which in turn are shaping international trade and innovation policies. The scale of the consumption of materials in industry is such that it is facing important challenges in environmental and ecological sustainability. The semiconductor industry is now responsible for up to 5% of all global emissions and plastics alone might contribute up to 30% of all emissions by 2050[2]. Without very considerable change in our approach to the extraction, modification and consumption of materials, 2050 climate targets will not be met.

The importance of materials science to Ireland as a small export-led economy is very significant and the need to nurture the sector is a pre-requisite for economic resilience and success. **Recent analysis by Statista shows that in 2024 the value-added materials products market is around $14 billion pa to the Irish economy with a total volume of around $41 billion pa with over 8000 companies and 70,000 employees[3].** It is the single biggest contributor to our high value manufacturing sector. Ireland's heavy dependence on trade, (imports and exports) and foreign direct investment (FDI) means that our economy is highly vulnerable to emerging developments in global value chains and protectionism policies. Our track record in attracting and supporting growth of FDI companies has undoubtedly bolstered growth & innovation. However, Ireland's attractiveness to future investment is directly linked to the ability to adapt and transition towards sustainability - which will become a significant factor in future investment decisions. Such challenges can only be met by being at the forefront of materials science and engineering in industry and academia. The creation of SFI in 2003, and subsequent investment in individual and centre led research programmes has provided the platform and investment to allow Irish researchers to establish international reputation for materials science research, however, it will be essential to sustain and build on this platform of funding to ensure we remain competitive and can advantage emerging opportunities across the manufacturing sectors and in particular in relation to the green and digital "twin transition" where is it estimated that 70% of all associated innovations will rely on advanced materials[4].

1 OECD (2019), Global Material Resources Outlook to 2060: Economic Drivers and Environmental Consequences, OECD Publishing, Paris, https://doi.org/10.1787/9789264307452-en.

2 Freitag, C. , Berners-Lee, M , Widdicks, K. Knowles, B. Blair, G, Friday, A.. (2021).Patterns. 2. 100340. 10.1016/j.patter.2021.100340

3 Material products - Ireland: Statista market forecast. Statista. (n.d.). https://www.statista.com/outlook/io/manufacturing/material-products/ireland

4 Draft concept papers for Proposed European Partnership "Innovative Materials for EU" ("I'M for EU"). Co-funded and co-programmed European Partnerships under the second Horizon Europe Strategic Plan

This report provides an analysis of the state of materials science research and innovation in Ireland, its importance to and its support of the national economy and its priority within the EU. The report makes the case for a **national strategy** driven by multiple stakeholders from academia, industry, and public sector to inform policy, prioritisation, future support, and funding for this area of national importance. A strong, internationally competitive materials science research, innovation and education capacity will be a necessity to deliver on the ambition of IMPACT 2030[5], the Whitepaper on Enterprise[6] the Climate Action Plan[7] and our national priorities with respect to competitiveness, advancing our value proposition to FDI, strengthening our indigenous exporting sector, addressing climate change, and delivering an innovative healthcare system.

In February 2024, the European Commission launched the Communication for Advanced Materials for Industrial Leadership as part of the European Critical Raw Materials Act[8] which intends to harness Europe's strengths in disruptive research and enhance the capacity for translation and commercial exploitation across the region. This will involve a coordinated approach across the members states with the formation of a Technology Council for Advanced Materials to align on EU, national and regional priorities on research and innovation with the provision of digital and physical infrastructure with financing provided through a number of Europe Instruments. As a small member state, it is important that Ireland has active representation and participation on the proposed Technology Council for Advanced Materials supported by a clearly defined **national strategy** which is aligned to our strategic priorities. This will ensure that we continue to influence the emerging policies that will govern European innovation, industry and trade policies relating to advanced materials.

This report makes some Key Recommendations:

- **A national stakeholder group across academia, industry and Government should be created to inform policy and funding for materials science and ensure Ireland remains a world leader in this field.**
- **Dedicated, sustained and predictable research funding for materials science is essential. A strong national research centre should be supported as a national priority.**
- **Ring-fenced funding should be delivered aimed at priority areas within the broader materials science field.**
- **There should be a focus on renewing the national infrastructure supporting materials science research and innovation. Significant funding is required if this is to be consistent with other world-class centres.**
- **There should be an associated materials training strategy developed, funded from the National Training fund. This should span diploma, MSc, and PhD schemes in addition to Continuous Professional Development (CPD) training to upskill the existing workforce.**

5 Department of Further and Higher Education, Research, Innovation and Science. (2022b, May 18). Impact 2030 – Ireland's Research and Innovation Strategy 5. https://assets.gov.ie/224616/5f34f71e-e13e-404b-8685-4113428b3390.pdf

6 White Paper on Enterprise 2022-2030 (2022). Department of Enterprise, Trade and Employment. Retrieved December 10, 2023, from https://enterprise.gov.ie/en/publications/white-paper-on-enterprise-2022-2030.html.

7 Department of Environment, Climate and Communications. (2023, December 20). Climate Action Plan 2024. https://www.gov.ie/en/organisation/department-of-the-environment-climate-and-communications/. https://assets.gov.ie/284675/70922dc5-1480-4c2e-830e-295afd0b5356.pdf

8 COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS Advanced Materials for Industrial Leadership (2024). Retrieved March 4, 2024, from https://research-and-innovation.ec.europa.eu/document/download/0fcf06ea-c242-44a6-b2cb-daed39584996_en.

Outline and Objectives of this Paper:

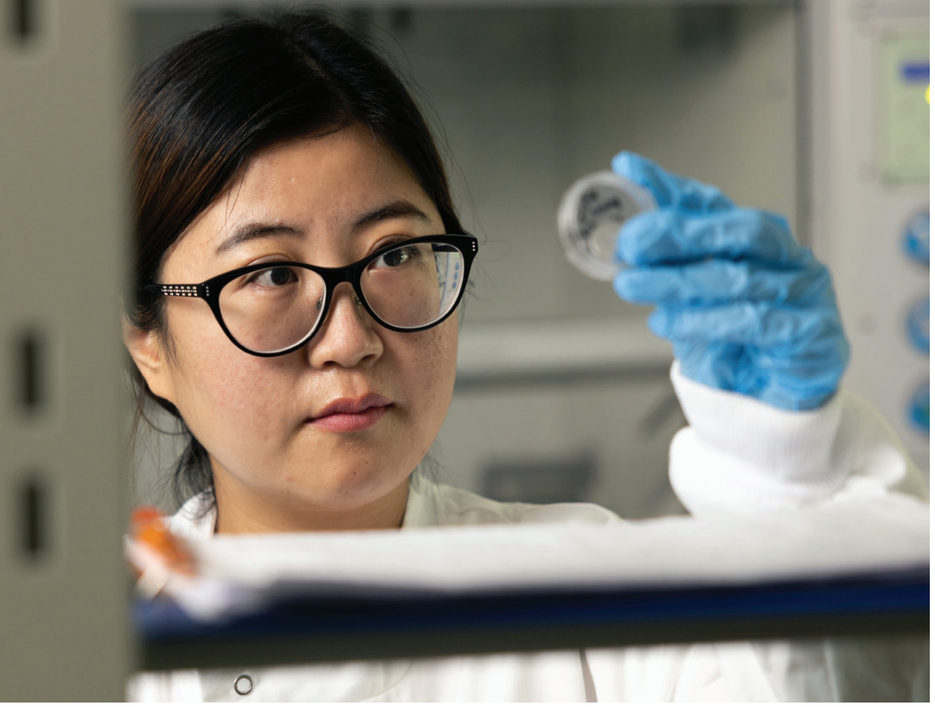
Ireland has a vibrant export driven economy reliant on the high-tech manufacture of goods and services. **The Manufacturing sector comprises 41% of our GDP[9] exports goods of a value of €200 billion annually and employs over 275,000 people[10].** Advanced Materials are a key enabling technology underpinning manufacturing and consequently has been a research priority for Ireland since 2012 and the country has an established international reputation in this area. This capability has supported our manufacturing sector in the development of innovative high-performance products and providing a pipeline of skilled scientists to these companies. The term "materials transition" is being used to describe how advanced materials innovation, manufacturing and product manufacturing is recognised as a key enabling technology for driving economies that are more environmentally conscious, consistent with climate targets whilst enabling sustainable economic development. **By recognising the significance of materials science across the entire value chain, Ireland has the opportunity to position itself as a leader in technological advancement and product innovation on the global stage.**

Irish enterprise, innovation and environmental policies place a high priority on transitioning the industry and research base to a low carbon, sustainable and innovation-driven model with increased international reputation and global competitiveness. This strongly resonates with the national research priority areas of Materials and Manufacturing which is supported by thriving research ecosystem including the National scale SFI centres for Advanced Materials and Bioengineering research (AMBER) and Advanced Manufacturing (I-Form) as well as the Enterprise Ireland funded Technology centre - Irish Manufacturing research (IMR) and Gateways including the Centre for Research in Engineering Surface Technology (CREST) Gateway, South Eastern Applied Materials (SEAM) and Applied Polymer Technologies, and national research performing organisations (RPO) NIBRT and the Tyndall National Research Institute. In the case of materials, the vulnerabilities to disruptions within global supply chains is particularly acute for the Irish manufacturing sector due to a high dependency on the import of raw materials. This could potentially impact productivity, increase costs and affect competitiveness. **Having a strong national competency in materials science and research will be pivotal to drive innovation in the areas of sustainability, circularity and substitution technologies which will underpin future supply chains of our manufacturing industries.** This may shape our future value proposition for Foreign Direct Investment (FDI) and our aspirations for the Irish-owned exporting sector.

This paper will examine the value proposition and business case for increased Government investment in materials science research, innovation, and education in Ireland, addressing the relevance to national priorities in the economy, enterprise, healthcare, climate action and skills. It will outline the importance and need for investment across 1) early-stage fundamental research to application driven collaborative programmes, 2) benchmark Irish research with international competitors and best practice in the field and 3) will evaluate the alternatives and associated risks of decreasing investment in this pivotal area.

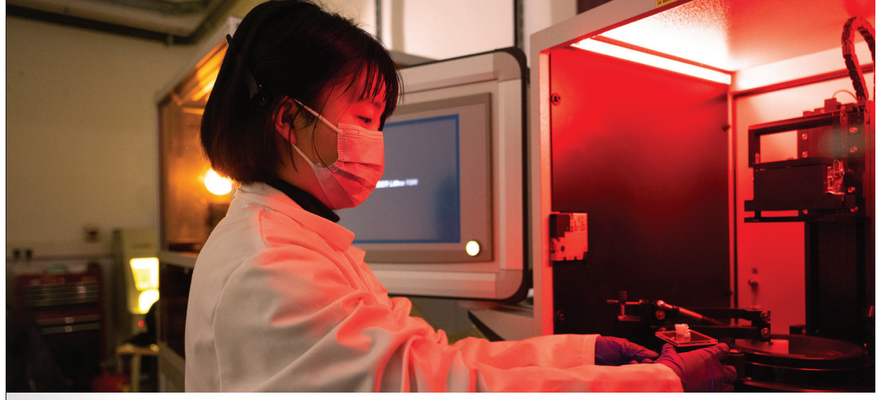
9 Industry (including construction), value added (% of GDP) - Ireland. World Bank Open Data. (n.d.). https://data.worldbank.org/indicator/NV.IND.TOTL.ZS?locations=IE

10 Ibec. (2023, October). Ibec's latest report 'manufacturing in Ireland – unlocking Ireland's manufacturing potential for the next manufacturing evolution' .https://web.ibec.ie/cn/agzlc/manufacturing?_ga=2.169693921.1798663038.1711105185-522045278.1711105185



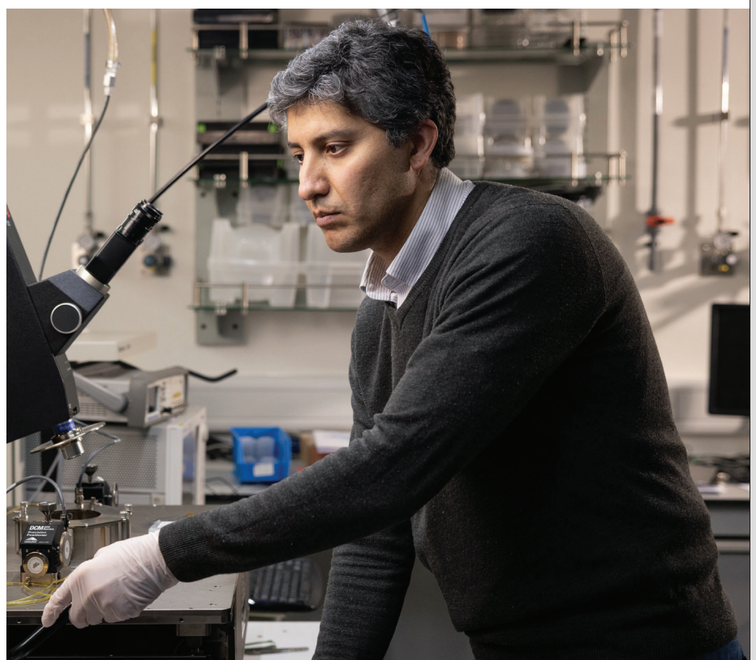
"In the material sciences these are and have been, and are most surely likely to continue to be heroic days."

— J. Robert Oppenheimer



"As we gain more knowledge about materials and processes in the universe, that could open up benefits that we can't even imagine. But you have to be willing to fund science without knowledge of the benefits."

— Fred Kavli



—01 What is materials science and why is it important?

Materials science is the study of solids, their properties, and applications.

These materials may be natural (e.g. minerals or biological in origin), processed or synthetic. Many technologies are based on material discovery and innovation. This is a multidisciplinary field encompassing physics, chemistry, engineering, and other scientific disciplines focused on understanding and exploiting the relationship between the atomic or molecular structure of materials and their macroscopic properties and functional behaviour for their specific applications. Materials science is the control of a material's atomic or molecular structure used to define their functionality. As an example, to illustrate how engineered materials are needed to define the functionality of product we can consider the material components of a car body. They must be light to minimize energy use, strong enough to survive collisions and support car parts and people, corrosion resistant and be recyclable for continued use. As materials have improved, we have seen lower fuel use and performance warranties of up to 12 years. All the result of materials advances and new processing technologies.

The field of materials science spans a diverse range of material classes from metals and ceramics to polymers and biomaterials. They are used as powders, substrates, solids, fabrics, and many other forms. **Synthetic or highly modified raw materials are collectively known as Advanced Materials and these engineered materials have been at the forefront of technological and societal progress throughout history from early stone age tools to the development of quantum computing.** They are research intensive and a critical element of the wider materials markets.

Advanced materials are the basis of modern technologies and all manufacturing industries including catalysis, adhesives, semiconductors, renewable energy, automotive, aeronautic, pharmaceuticals, med-tech, agritech and food. They are intrinsically linked to manufacturing and economic growth being a driver for innovation and industrial competitiveness forming the backbone of the export sector. According to one market research company the global advanced materials market is estimated to be valued at $513.1 billion in 2023 and is projected to reach $ 695.5 billion by 2028, at a CAGR of 6.2% from 2023 to 2028[11]. In the wider context, advanced materials are a key enabling technology for a $ multi-trillion manufacturing sector spanning industries such as medical devices, semiconductors, food and medical packaging, and construction summarised in **Table 1.** **Growth in materials related sectors is being fuelled by the green and digital transitions and it is thought that 70% of the associated innovations will depend on materials[4].** On an international scale, the strategic relevance of advanced materials innovation and translation capabilities to trade and economic policies is recognised through large scale, multi-stakeholder strategies focused on the deployment and optimisation of policy, infrastructure and resources to accelerate the development and deployment within a region. These include the US Materials Genome Initiative Strategic Plan[12] and the recently published EU communication, Advanced Materials for Industrial Leadership[8] which aims to create an advanced materials ecosystem coordinated across all of the member states so as to align on EU, national and regional research and innovation priorities for advanced materials.

11 Global Market Estimates. (2024, March 14). Advanced materials market analysis: Size & forecasts. Global Market Estimates Research & Consultants. https://www.globalmarketestimates.com/market-report/advanced-materials-market-3932

12 (2021) Materials genome initiative strategic plan - mgi.gov. Available at: https://www.mgi.gov/sites/default/files/documents/MGI-2021-Strategic-Plan.pdf (Accessed: 12 February 2024).

The preliminary priority areas of renewable energies, transport, construction home and electronic appliances have been identified as the primary targets of this communication. Specific use cases of high priority for Ireland and its industry base include the following:

— **Advanced materials for renewable energy production technologies;** By 2050 90% of electricity generation in Europe will come from renewable sources, with wind and solar together accounting for nearly 70%, this will include Ireland's target of 80% of renewables and a wind generation capacity of 8GW onshore and 5GW offshore by 2030. It is estimated that materials related sectors will represent between 50-70% of the energy market turnover[13].

— **Advanced materials for improved energy storage** (at lower costs and using more sustainable technologies to facilitate integration of renewables into the grid and the deployment of electric vehicles. These include post lithium-ion battery technologies, electrode and membranes for hydrogen production and novel cathode/anode materials for energy storage devices, essential elements of our Climate Action Plan (2021).

— **Materials for energy efficient, low carbon footprint buildings** including low carbon and renewable construction materials, integrated photovoltaics, advanced insulation, smart lighting, and advanced glazing. Demand will be driven by emerging policies and regulation including our national target of 10% decrease in embodied carbon in construction materials by 2030.

— **Materials for sustainable packaging, which is fit for purpose,** designed for circularity and recycling, compliant with European regulations for the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH standards) and suitable for use in multiple sectors including agriculture, food, MedTech, pharma and consumer goods. This will be essential for Irish industry to achieve the Climate Action Plan target of ensuring all plastic packaging is reusable or recyclable by 2030.

— **Materials for low power, high performance information and communications technologies,** including semiconductor chips, which will be critical for the European electronics industry to meet European Chips Act Goal of doubling current market share to 20% by 2030. This is of particular significance to Ireland with a sector providing over 20,000 high skilled jobs and contributing €13.5bn in export revenue and €450m of R&D spend annually[14].

— **Materials for health including engineered biomedical materials and implants to estore function following disease or injury** and improved diagnosis and treatment of patients with both acute and chronic conditions including those associated with ageing. Ongoing research in Ireland is informing the next generation of medical technologies including the development of digitally enabled medical implants, systems and platforms and advanced therapy medicinal products which combines cells, genes, and materials for drug delivery. The medical technology sector is one where Ireland has an established global leadership position, with 450 companies employing 42,000 people and contributing over €12 billion in export revenue[15]. Ireland is home to 14 of the top 15 global MedTech companies – spanning multiple sites across the country and ever-increasing R&D by the MNC sector is now driving the formation of numerous new indigenous start-ups and SMEs1[6].

— **Materials for new disruptive and unconventional technologies,** such as novel superconductors and superconductor heterostructures for quantum computing, semiconductor/metal high integration for cryogenic electronics, semiconductor/optical stacks for coherent quantum communication.

Market Sector	Value (B$) (2021/2022)	% Growth Rate (to 2030)
Semiconductor materials[17]	58.3	4.6
Medical device materials[18]	512.3	7.8
Healthcare packaging materials[19]	134.0	4.1
Ceramic materials[20]	239.5	5.2
Food packaging materials[21]	338.34	5.1
Sustainable packaging materials[22]	336.7	10.3
Construction materials [23]	1320.0	3.9
Sustainable construction materials[24]	297.5	12.7

Table 1: The global materials industry and important sectors relevant to Ireland

13 INTERNATIONAL ENERGY AGENCY. (2021, October). Net zero by 2050 - A Roadmap for the global energy sector. www.iea.org. https://iea.blob.core.windows.net/assets/deebef5d-0c34-4539-9d0c-10b13d840027/NetZeroby2050-ARoadmapfortheGlobalEnergySector_CORR.pdf

14 MIDAS Ireland (January 2021) . Electronics Sector Resources & Skills Needs https://midasireland.ie/wp-content/uploads/2021/01/Electronics-Sector-Resources-Skills-Needs-Report-Rev5.1-Web-Optimised-1.pdf (accessed 1 Sept 2023)

15 Irish Medtech Association (IBEC) , The Global Medtech Hub 2025 (March 2022), https://www.ibec.ie/-/media/documents/media-press-release/irish-medtech-association---the-global-medtech-hub-2025.pdf . (accessed 1 Sept 2023)

16 Ireland's Medtech Sector | IDA Ireland. IDA Ireland. (n.d.). https://www.idaireland.com/explore-your-sector/business-sectors/medtech/

17 Semiconductor materials market (by product type: Fab materials, packaging materials; by application: Computers, Communications, Consumer Goods, Defense & Aerospace, other; by material: Silicon Carbide, gallium manganese arsenide, copper indium gallium selenide, molybdenum disulfide, bismuth telluride) - global industry analysis, size, share, growth, trends, regional outlook, and forecast 2023 – 2032. Precedence Research. (2023, September). https://www.precedenceresearch.com/semiconductor-materialsmarket#:~:text=The%20global%20semiconductor%20materials%20market,forecast%20period%202022%20to%202030

18 Medical devices market share, growth, trends: Forecast [2030]. Medical Devices Market Share, Growth, Trends | Forecast [2030]. (2023, May). https://www.fortunebusinessinsights.com/industry-reports/medical-devices-market-100085

19 Global Market Estimates. (2024, March 14). Advanced materials market analysis: Size & forecasts. Global Market Estimates Research & Consultants. https://www.globalmarketestimates.com/market-report/advanced-materials-market-3932

20 Ceramics market size, Share & Growth Analysis Report, 2030. Ceramics Market Size, Share & Growth Analysis Report, 2030. (2023). https://www.grandviewresearch.com/industry-analysis/ceramics-market

21 Food packaging market size, share, Trends & Growth [2030]. Food Packaging Market Size, Share, Trends & Growth [2030]. (2023, December). https://www.fortunebusinessinsights.com/industry-reports/food-packaging-market-101941

22 Market Research Future. (2023, April 25). Sustainable packaging market to capture a cagr of 10.30% while touching approximately USD 737.6 billion by 2030 – report by Market Research Future (MRFR). GlobeNewswire News Room. https://www.globenewswire.com/en/news-release/2023/04/25/2654133/0/en/Sustainable-Packaging-Market-to-Capture-a-CAGR-of-10-30-While-Touching-Approximately-USD-737-6-Billion-by-2030-Report-by-Market-Research-Future-MRFR.html

23 Construction materials market size: Global industry report 2032. Construction Materials Market Size | Global Industry Report 2032. (2023, March). https://www.fortunebusinessinsights.com/construction-materials-market-107415

24 Sustainable construction materials market. Transparency Market Research. (2023, January). https://www.transparencymarketresearch.com/sustainable-construction-materials-market.html

—02 The Need for Materials Innovation in Ireland and Internationally

Global population and economic growth driving increased materials consumption

Economic, geopolitical, and societal factors are driving an unprecedented demand for materials. **The OECD have forecasted that due to continued population growth and convergence of living standards, the global demand for raw materials will rise from 89 Gt in 2017 to 167 Gt in 2060[1].** The increased consumption of resources is being further accelerated through the rapid deployment of technologies associated with energy and digital transitions including photovoltaics, electric motors, semiconductors, and data transmission networks all of which are materials intensive with a significant dependency on critical raw materials which are located in limited areas of the globe. For example, current predictions indicate global demand for the lithium used to manufacture batteries will increase up to 89-fold by 2050[25]. Within the EU, demand for the rare earth elements used in the electric motors driving wind turbines and electric vehicles is expected to increase six-seven fold and demand for gallium, used to manufacture semiconductors, is expected to grow 17-fold by 2050[25,26]. For plastics, ubiquitous to all sectors, the OECD are projecting a threefold increase in the global production and use from 460 million tonnes (Mt) in 2019 to 1,231 Mt in 2060[27]. This is forcing increased global competition for finite resources resulting in significant challenges in terms of supply chain vulnerabilities and the consequential impacts on the environment and sustainability which in turn are shaping international trade and innovation policies. This is exceptionally important for Ireland as we are a net importer of materials and highly reliant on supply.

Protection of vulnerable supply chains and impact on international trade policies

The model of globalisation of the supply of materials has been challenged by intense supply chain disruptions caused by events such as Covid-19, the evolving US-China trade war, Russia's invasion of Ukraine and the sanctions that followed. Policy makers are now being forced to respond and deal with those supply chain risks and challenges, and the associated economic vulnerabilities. Several nations, including the European Union members, United States, China, Japan, and South Korea, are taking steps to secure their supply chains by reducing reliance on external sources. This is particularly acute within Europe which has a high dependency on raw and processed materials imports from China and oil and gas from Russia and is, thus, increasingly susceptible to supply chain disruptions due to geopolitical issues. In June 2023, the European Commission adopted regulation under the Critical Raw Materials Act designed to ensure a secure and sustainable supply of **critical raw materials**[26]. The act identifies a list of 34 critical raw materials, which are important for the EU economy and face potential supply issues, of which 17 are designated "strategic" because of their importance to Europe's green and digital ambitions and vulnerability to global demand. These include aluminium, copper, and nickel, along with key battery material lithium and rare earth elements used in permanent magnets for wind turbines or in electric vehicles.

25 Carrara, S., Bobba, S., Blagoeva, D., Alves Dias, P., Cavalli, A., Georgitzikis, K., Grohol, M., Itul, A., Kuzov, T., Latunussa, C., Lyons, L., Malano, G., Maury, T., Prior Arce, À., Somers, J., Telsnig, T., Veeh, C., Wittmer, D., Black, C., Pennington, D., Christou, M., Supply chain analysis and material demand forecast in strategic technologies and sectors in the EU – A foresight study, Publications Office of the European Union, Luxembourg, 2023, doi:10.2760/386650, JRC132889.

26 REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL establishing a framework for ensuring a secure and sustainable supply of critical raw materials and amending Regulations (EU) 168/2013, (EU) 2018/858, 2018/1724 and (EU) 2019/1020. EUROPEAN COMMISSION. (2023, March 16). https://single-market-economy.ec.europa.eu/document/download/a54c7d84-9bf6-41eb-a60e-fe70c86888dc_en

27 OECD (2022) Global Plastics Outlook: Policy Scenarios to 2060, OECD Publishing https://www.oecd-ilibrary.org/sites/aa1edf33-en/index.html?itemId=/content/publication/aa1edf33-en&_

The regulation sets the following benchmarks for domestic capacities along the strategic raw material supply chain and to diversify EU supply by 2030:

- At least 10% of the EU's annual consumption should be mined in Europe.
- At least 40% of the EU's annual consumption should be processed in Europe.
- At least 15% of the EU's annual material consumption should come from recycling.
- No more than 65% of the EU's annual material consumption from a single third country.

In accordance with the Green Deal Industrial Plan, the Critical Raw Materials Act, the Commission's proposed Net Zero Industry Act that provides for scale-up of carbon-neutral renewable energy and the Circular Economy Action Plan, the Critical Raw Material Act sets a target for European manufacturers to produce 40% of the EU's annual needs of clean tech products, such as solar and wind power systems, battery storage and fuel cells and a goal of reaching 50 million tonnes of annual storage capacity of carbon dioxide by 2030. These targets underpin European research and innovation priorities for advanced materials. Within the Horizon Europe work programme a budget of €470M has been allocated to projects on material exploration, extraction, processing and reuse, recycling and recovery and substitution[28]. This is accompanied by a parallel investment in education and skills including establishing a Raw Materials Academy and linkages to the Deep Tech Talent Flagship Initiative led by the European Institute of Technology and Innovation (EIT) aiming to train one million people in deep tech fields over the next three years.

The recent announcement on the European communication for Advanced Materials for Industrial Leadership[3] reflects the importance of advanced materials as a critical technology area for the Union's economic security. The communication looks to harness Europe's strengths in disruptive research to fast track the transfer of that research to industry for commercial exploitation. It will create an Advanced Materials ecosystem in Europe involving a coordinated approach across the Commission and the members states aiming to align on EU, national and regional priorities on research and innovation with the provision of digital and physical infrastructure to sponsor "lab to fab" innovations and the creation of a new co-programmed Horizon Europe partnership. This partnership 'Innovative Materials for EU #IM4EU4[4] is a €500M investment with matching industry contribution and future potential engagement with the large-scale Important Projects of Common European Interest (IPCEI) programme and the European Innovation Council.

There are other international policies that stress the importance of materials in economic health. In the US there is an emerging concept of Friend-shoring which encourages companies to shift manufacturing from authoritarian states towards friendly countries. A specific example of this is the legislation and funding being put in place in the US, Europe, and Japan to address global supply vs demand discrepancy for semiconductor chips. Recent global semiconductor shortages have forced factory closures across a range of sectors, from cars to healthcare devices. In the US, the CHIPS and Science Act is a U.S. federal statute signed into law by President Joe Biden on August 9, 2022. The Act provides an estimated $50 billion in new funding to boost domestic research and manufacturing of semiconductors in the United States.

28 COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS; A secure and sustainable supply of critical raw materials in support of the twin transition, 16 March

Similarly, the European Chips Act aims to address semiconductor shortages and strengthen Europe's technological leadership. It will mobilise more than €43 billion of public and private investments and set measures to prepare, anticipate and swiftly respond to any future supply chain disruptions, together with Member States and the EU's international partners. The aims are to strengthen Europe's research and technology leadership; increase European production capacity to 20% of the global market by 2030; build and reinforce capacity to innovate in the design, manufacturing, and packaging of advanced chips; develop an in-depth understanding of the global semiconductor supply chains; and address the skills shortage, attract new talent, and support the emergence of a skilled workforce. As an important centre for semiconductors, Ireland should be at the centre of this EU policy, but this will require ongoing strong investment in science and research.

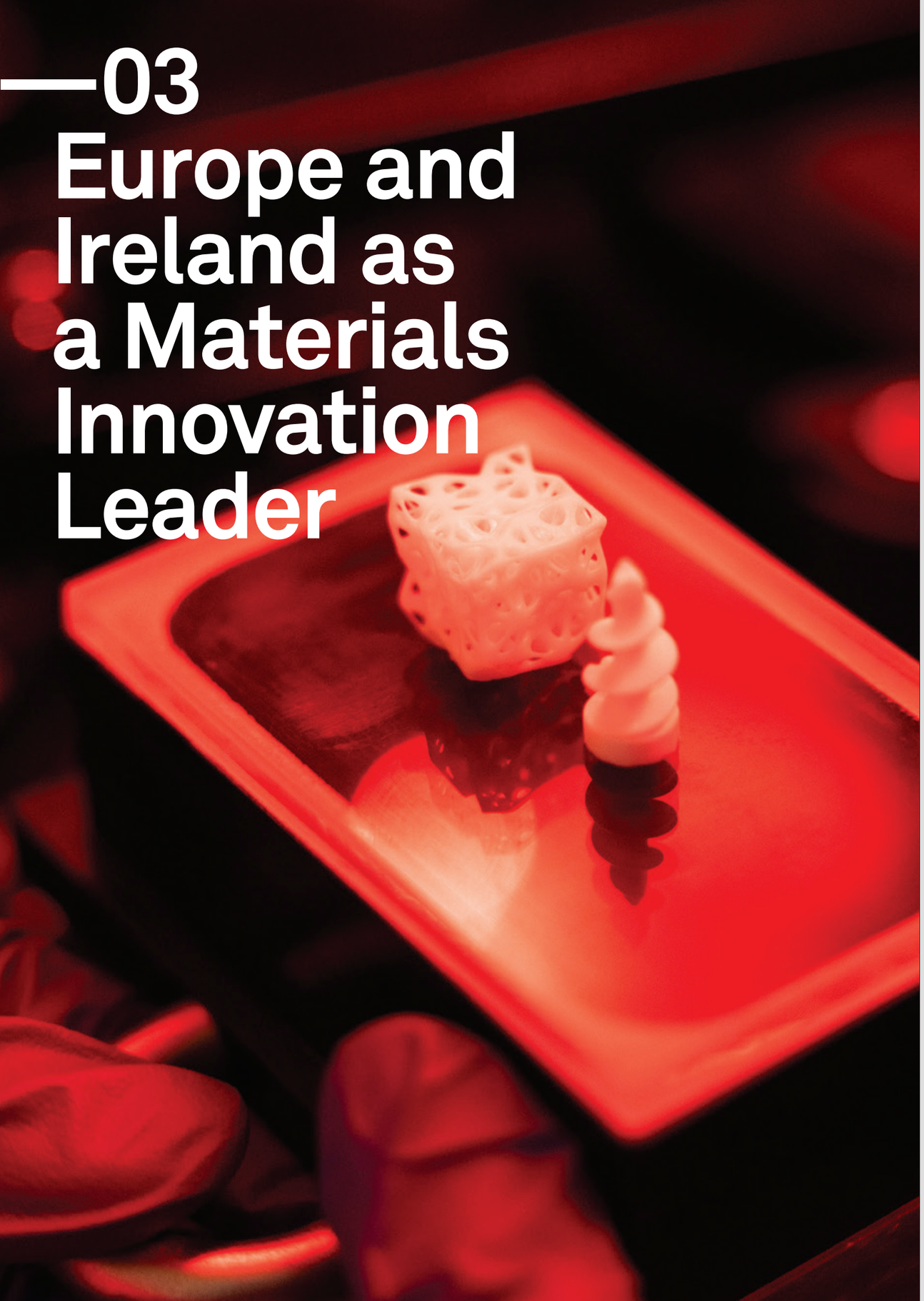
Climate change against a backdrop of economic development

The Paris Climate Agreement is a legally binding international treaty on climate change. It was adopted by 196 Parties at COP 21 in Paris on 12th December 2015 and entered into force in November 2016[29]. Its goal is to limit the global average temperature rise in this century to below 1.5C, compared to pre-industrial levels. To achieve this long-term temperature goal, countries should achieve a 'climate-neutral' society by 2050. The significant increase in materials demand is creating significant environmental pressures, **the OECD are projecting total green house gas (GHG) emissions to reach 75 Gt CO2(eq) by 2060 of which 50 Gt CO2(eq) is associated with "materials management**[1].

Decoupling materials consumption from economic growth and technology advancement while minimising the impact on climate, the environment and human health and well-being is a grand challenge that informs all innovation in this field. A clear priority in meeting the demands of our climate commitments is the design of materials with enhanced sustainability, durability and circularity that can be substituted for primary raw materials in critical technologies with equivalent or better performance to ensure they remain in circulation for as long as possible whilst reducing waste. This is a real challenge requiring disruptive approaches such as artificial intelligence and new technologies such as alternatives for lithium-ion batteries.

29 United Nations. (2016, April 22). The Paris Agreement. United Nations. https://unfccc.int/sites/default/files/english_paris_agreement.pdf

—03 Europe and Ireland as a Materials Innovation Leader



Advanced Materials are both a competitive strength and a strategic priority in the European Union. The region is a global leader in materials innovation holding 20-25% of international patents and with levels of venture capital investment, suppliers and share of skilled professionals equivalent to the US and higher than Asia including China[30]. However, despite these strengths there are acknowledged weaknesses in the areas of scale up and production[31]. To ensure Europe retains its technology leadership position and enhance translation and commercialisation, the Advanced Materials for Industrial Leadership communication[8] will align research and innovation priorities and investments in the EU. The communication is organised around the following five pillars.

— 01 Strengthen R&I on Advanced Materials

European R&I for Advanced Materials to foster innovation and manufacturing capacity on advanced materials and strengthen the European cientific base. This will involve coordination across the member states aiming to align objectives and priorities on R&I investments. There will be a particular focus here on the R&I needs to replace critical raw materials

— 02 Fast track from Lab to Fab

Fast track from lab to fab – to accelerate the scale up and manufacturing capacity (from lab to fab) of advanced materials. This will focus on 2 areas – use of digital infrastructure and AI to accelerate new materials discovery and uptake and providing access to technology infrastructures, to support companies in commercialise innovation in advanced materials.

— 03 Access to Finance

Increasing capital investment and access to finance – including mobilising €500M investment between 2025-2027 through a co-programmed public-private partnership ‘Innovative Materials for EU’ proposed under Horizon Europe focused on scaling and accelerated deployment of advanced materials. Future alignment with Important projects of common European interest (IPCEI), European Innovation council, innovation fund and Strategic Technologies for Europe Platform (STEP) are also planned.

— 04 Production and Use

Fostering the production & use of advanced materials – this will include working with public procurement schemes, the development of international standards, a focus on skills through the setup of an Advanced Materials Academy and a focus on our IP and patent landscape.

— 05 Governance Framework

Establishing of a Technology Council for Advanced Materials composed of Member States to provide advice on the European advanced materials ecosystem, support the identification of common objectives and priority areas for coordinated action in advanced materials

30 Smit, S., Tyreman, M., Mischke, J., Ernst, P., Hazan, E., Novak, J., Hieronimus, S., & Dagorret, G. (2022, September 22). Securing Europe’s competitiveness: Addressing its technology gap. McKinsey & Company. https://www.mckinsey.com/business-functions/strategy-and-corporate-finance/our-insights/securing-europes-future-beyond-energy-addressing-its-corporate-and-technology-gap

31 European Innovation Council and SMEs Executive Agency (EISMEA), Izsak , K., Carosella, G., Micheletti, G., Kroll, H., Wydra, S., & van de Velde, E. (2021, October 18). Advanced Technologies for Industry, Report on technology trends and technology adoption. Publications Office of the EU. https://op.europa.eu/en/publication-detail/-/publication/5976f0f1-308a-11ec-bd8e-01aa75ed71a1/language-en

Ireland, through DFHERIS, our funding agencies the Horizon Europe National Support Network, the SFI centres including AMBER and I-Form and our FDI and SME industry stakeholders have been active participants in the definition of this communication through our participation in the Advanced Materials 2030 Initiative (AMI2030) and our contribution to the publication of the Strategic Materials Roadmap and Agenda in 2023[32]. **As one of the smaller member states of the EU27 it is critically important that we continue to engage with the EU-wide materials community across our public sector, academic and industry stakeholders to ensure our relevance and national priorities are reflected in future European materials related R&I strategies and policies.**

Ireland and its international standing in the materials innovation ecosystem

Advanced Materials have been identified as a research priority for Ireland since 2012[33] reflecting the importance of the field to the future competitiveness and sustainability of the Ireland's manufacturing sector. This sector forms the backbone of the Irish economy accounting for almost 38% of national GDP (more than twice the EU average)[34], employing 275,000 people and contributing 44% of the annual Corporation Tax intake[35]. This prioritisation recognised the pre-existing national strengths in Materials science and provided targeted funding to support the ongoing development of a strong research and innovation ecosystem spanning academia and enterprise with the intent of increasing out international reputation and competitiveness in the field and enhancing the innovative capacity of Irish based manufacturing companies.

The SFI centres AMBER (Advanced Materials and Bioengineering Research) and I-FORM (Advanced Manufacturing) focus on breakthrough research and its translation into applications and commercial demonstration in collaboration with Industry and other stakeholders. National research institutes such as NIBRT, the Tyndall National Institute and IMR provide the critical mass, infrastructure, and expertise to translate research from early stage to pilot production. Ireland has established international reputation for excellence in materials science research. This excellence is indicated by the national average field weighted citation impact (FWCI) in the Materials Science Field from 2013-2022 as shown in Figure 1. FWCI represents the number of citations associated with a scientific publication relative to the average citations over the previous three years thus a FWCI of more than 1 indicates higher than expected citations based on the global average. As can be seen in the figure Ireland's performance in materials science is ranked towards the higher end of the EU28 and OECD group countries, at an equivalent level to North America, Denmark, Belgium, and the Netherlands as recognised global leaders in this field.

32 AMI2030, Materials 2030 Roadmap December 2022 https://www.ami2030.eu/wp-content/uploads/2022/12/2022-12-09_Materials_2030_RoadMap_VF4.pdf

33 Department of Trade, Enterprise, and Employment. (2018, March 14). Research priority areas 2018 to 2023 . https://dbei.gov.ie/en/Publications/Publication-files/Research-Priority-Areas-2018-to-2023.pdf

34 Ireland - manufacturing, value added (% of GDP)2024 data 2025 forecast 1995-2022 historical. Ireland - Manufacturing, Value Added (% Of GDP) - 2024 Data 2025 Forecast 1995-2022 Historical. (n.d.). https://tradingeconomics.com/ireland/manufacturing-value-added-percent-of-gdp-wb-data.html#:~:text=Manufacturing%2C%20value%20added%20(%25%20of%20GDP)%20in%20Ireland%20was%20reported,compiled%20from%20officially%20recognized%20sources. Accessed 19th February 2024.

35 Ibec's latest report 'manufacturing in Ireland – unlocking Ireland's manufacturing potential for the next manufacturing evolution' . Ibec. (2023, November 7). https://web.ibec.ie/cn/agzlc/manufacturing?_ga=2.230656478.330663234.1708355038-1446608040.1708355038

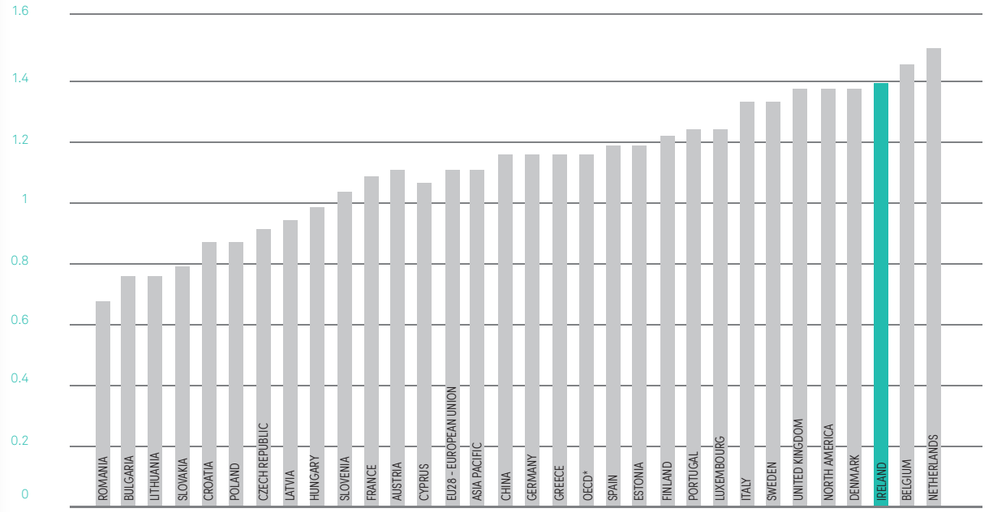


Figure 1: Average Field Weighted Citation Impact Country Level — Subject Area Materials Science, All Publications 2012-2022. Source Elsevier, Scopus, SciVal. Accessed November 2023

*Organisation for Economic Co-operation and Development

At an individual institution level, Figure 2 shows the Average Field Weighted Citation Impact (FWCI) of publications in the Materials Science field for the Top 50 Academic Institutions Globally for Materials Science according to QS rankings data (2023). We have included the FWCI score for the AMBER Centre (orange bar) at the higher end of the graph. This performance is equivalent to established global leaders, University of Cambridge, Swiss Federal Institute of Technology Lausanne (EPFL), University of Oxford & National University of Singapore. This data reflects Ireland's position as a leader in Materials Science Research and demonstrates the value of Ireland's approach of clustering of national expertise within the centre model as a means to enhance global academic competitiveness in this area.

Ireland has similarly performed relatively strongly for its population within the European Research and Innovation funding programmes. As shown in Figure 3, since 2004 Irish researchers have secured €777M in competitive research awards in fields related to materials science[36], When this data is normalised against the relative populations[37], Irelands performance in EU draw down is the third highest in Europe as illustrated in Figure 4, only behind Denmark and the Netherlands and ahead of Finland and Sweden all of which are categorised as innovation leaders.

36 Horizon Europe Dashboard R&I projects. (Accessed 15 February 2024) https://dashboard.tech.ec.europa.eu/qs_digit_dashboard_mt/public/sense/app/d58f3864-d519-4f9f-855e-c34f9860acdd/sheet/7a2acdb7-ee97-4161-affe-302abc4888bb/state/analysis

37 OECD (2024), "Data warehouse", OECD.Stat (database), https://doi.org/10.1787/data-00900-en (accessed on 15 February 2024).

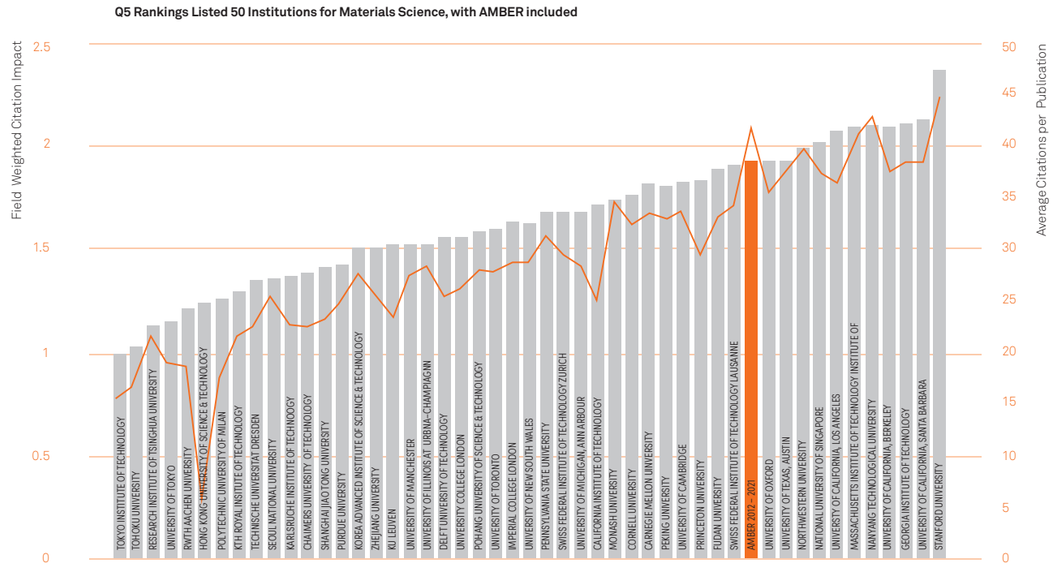


Figure 2: Average Field Weighted Citation Impact Institution Level - Subject Area Materials Science, All Publications 2012-2022. Institutions QS Rankings top 50 Academic Institutions for Materials Science. Source Elsevier, Scopus, SciVal. Accessed November 2023

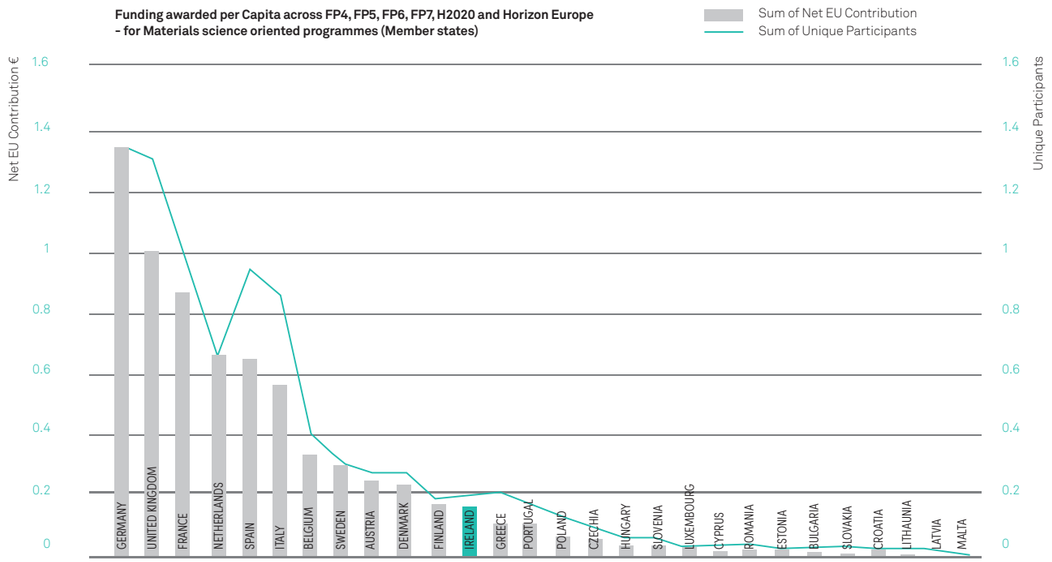


Figure 3: Country level performance within Materials Science Oriented programmes of the European Union Framework 4,5,6,7, H2020 and Horizon Europe Programmes including ERC , MSCA, Nanotechnologies and nanosciences, knowledge based multifunctional materials and new production processes and devices, Health, Nanosciences, Nanotechnologies, Materials and new Production Technologies – NMP, Advanced manufacturing and processing, Digital, Industry and Space, The European Innovation Council (EIC) (Source Horizon Europe Dashboard. Accessed Feb 24)

In summary, Ireland has a strong reputation both within Europe and globally for materials science research, both fundamental as reflected in our national publication metrics and success within the European Research Council funding programme (this is Europe's most prestigious research grant, focussed on disruptive, high-risk, high-gain, frontier research projects) and applied as reflected in our wider performance in the European research programmes. However, declining national funding for research in Ireland is reaching a sub-critical state and failure to reach European targets and our own commitment for research funding is challenging our reputation in this field because of lower PhD numbers, infrastructure investment and career progression for young researchers (further detail provided below).
As a small member state, it is essential to not only maintain but also to grow this reputation to ensure that we continue to influence the emerging European policies that will define and oversee advanced materials innovation and deployment in response to the international materials related challenges which in turn may govern future industry and trade policies in the region.

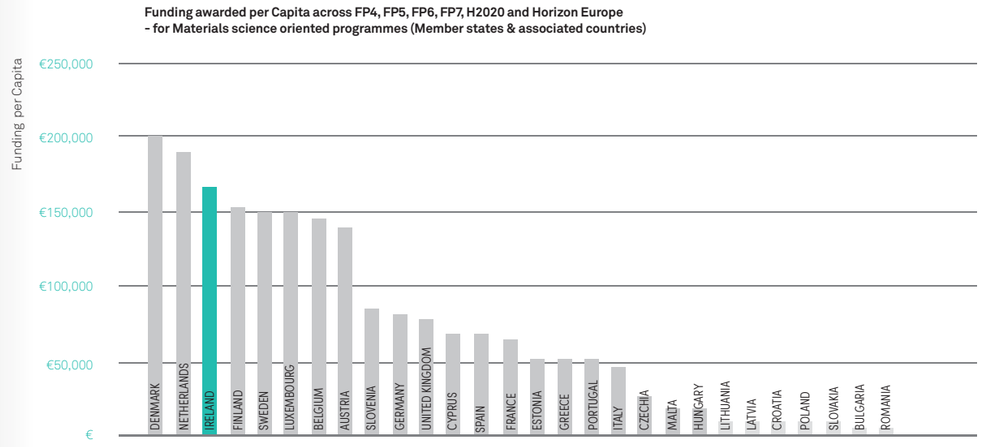


Figure 4: Funding per capita awarded to each Member state and associated countries wihtin Materials Science Oriented programmes of the European Union Framework 4,5,6,7, H2020 and Horizon Europe Programmes including ERC , MSCA, Nanotechnologies and nanosciences, knowledge based multifunctional materials and new production processes and devices, Health, Nanosciences, Nanotechnologies, Materials and new Production Technologies – NMP, Advanced manufacturing and processing, Digital, Industry and Space, The European Innovation Council (EIC) (Source Horizon Europe Dashboard. Accessed Feb 24)

—04 The Importance of Advanced Materials to Ireland and need for Investment

As a small open economy that is very dependent on trade and foreign direct investment as well as imports and exports, Ireland is well placed to exploit the opportunities associated with international trade policies and friend sharing but highly vulnerable to developments in global value chains. This is particularly relevant to the Irish manufacturing sector which accounts for 38% of our GDP[38]. Further emphasis and funding for the priority area of Advanced and Smart Manufacturing and Manufacturing and Novel Materials is a national research priority essential for our manufacturing base to build resilience against these international trends and compete and thrive in competitive international markets. At a policy level, Impact 2030, Ireland's Research and Innovation Strategy[5] and the Whitepaper on Enterprise 2022-2030[6] set out the vision and strategy for Ireland RD&I and Enterprise ecosystems which coalesce around the themes of international competitiveness (excellence), innovation, talent, the twin transition challenges of climate change and digitalisation and increased productivity for both FDI and indigenous enterprise.

A strong, internationally competitive materials cience research, innovation and education capacity is a necessity to deliver these national strategies in regard to the following:

- Economic Growth and Industrial Competitiveness
- Advancing Ireland's FDI.
- Strengthening the Irish-Owned Exporting Sector.
- Quality of labour supply.
- Addressing climate change, Sustainability and Environmental Protection.
- Energy security and energy infrastructure particularly national and international grid structure.
- Healthcare across the full range of demographics.

38 https://data.worldbank.org/indicator/NV.IND.MANF.ZS?locations=IE

National Competitiveness

International competitiveness is vital for economic success, particularly for a small, open, and globalised economy like Ireland. A nation's competitiveness demands productivity growth rates equal to or greater than those of its major competitors. The productivity growth rate is directly related to a country's rate of investment in innovation. It is well established that technological change is an important driver of total factor productivity. As far back as 1966, Simon Kuznets[39] produced landmark studies on the wealth of nations and stressed the pre-eminence of technology–

'we may say that certainly since the second half of the nineteenth century, the major source of economic growth in the developed countries as been science-based technology ……..'

The National Competitiveness and Productivity Council (NCPC) emphasises that increased competitiveness and improved productivity are key to maintaining economic prosperity and to allowing Ireland to build the infrastructure necessary to support economic and social wellbeing. In their 'Ireland's Competitiveness Challenge 2023 report'[40], the NCPC highlighted both the opportunities and risks for a small economy like Ireland in the wake of evolving global trade and protectionism policies. The report emphasises the importance and urgency of implementing appropriate polices to position Ireland to be a leader in breakthrough technology areas including decarbonisation, the circular economy and quantum computing all of which have a critical dependency on advanced materials innovation and expertise. In the view of the NCPC, this will be necessary to compete against larger countries for strategic investments associated with EU measures including the Chips Act and the Green Deal.

It is a certainty that the research funding into these critical areas is not consistent with Ireland being an international leader. These are new and emerging research areas in Ireland with expertise lacking and thus far no targeted funding of scale has been available.

It is important to stress that the Irish research funding landscape has worsened considerably since 2005 and Ireland performs relative poorly compared to other EU countries in terms of R&D investment. This weaker performance is evident when measuring as a percentage of GDP for other European countries and GNI* for Ireland which brings with it the associated risks and challenges to our aspirations as an innovation led economy.

- Failing to keep pace with other small, advanced economies in terms of investment in R&D represents a significant risk to Ireland's competitiveness and labour market productivity.
- The Impact 2030 strategy has committed to a target 'research intensity' rate of 2.5% of GNI* by 2030. This will require a significant increase with current reported levels of 1.78% of GNI* in 2022 and against recent annual figures which have decreased not increased.
- The NCPC notes that even of the 2030 target is achieved, it is modest relative to international standards and is below that of the OECD average of 2.7% in 2021 and significantly behind other small advanced economies, such as Sweden (3.3%), Finland (3%) and Denmark (2.8%).

39 Kuznets, Simon. 1966. Modern Economic Growth. New Haven: Yale University Press.

40 The National Competitiveness and Productivity Council (NCPC). (2023a, September 28). Ireland's Competitiveness Challenge 2023. https://enterprise.gov.ie/en/publications/publication-files/irelands-competitiveness-challenge-2023.pdf Accessed 21 Feb 2024.

It should also be recognised that Irish Government funding for research is disproportionately low relative to international benchmarks. Currently, Ireland has the highest ratio of Business Expenditure on R&D to Government Budget Allocations for R&D (BERD:GBARD) in Europe with 80.5% of the total national investment in Research and Innovation coming from the Business sector. **This means our funding for research and innovation makes us one of Europe's and the OECD lowest performing nations and well behind leading innovation countries such as Belgium, the Netherlands, Sweden, and Denmark**. Our Government Budget Allocation for R&D (GBARD) at 0.35% GNI* (estimated at €1,075m in 2023) significantly lags behind the EU 27 and OECD average of 0.71% and 0.6% respectively. Countries classified as innovation leaders are at least 2x the Irish investment with Denmark 0.92%, Finland 0.87, Sweden 0.76%, Netherlands 0.77%, and Belgium 0.7% GDP respectively. **This level of investment in R&D is simply not consistent with Ireland remaining a major leader in innovation in the future.** The NCPC, while acknowledging Ireland performs above the EU average in both the Global Innovation Index and European Index have highlighted the deterioration over a 5-year average with respect to its closest competitors. While still categorised a 'Strong Innovator' in the European Innovation Scoreboard 2023, our lead over countries ranked below us has narrowed, while the higher ranking "Innovation Leaders" have increased their lead[41]. Business and Public investment in R&D are not mutually exclusive but the delivery of new and disruptive innovations for business genesis and growth (particularly in the SME sector) requires Government investment. Achieving the IMPACT 2030 goals for 2.5% GNI* investment and in the doubling of BERD will not be possible without an accompanying increase in Government budget allocation to research carried out within the academia and other publicly funded institutions.

In the absence of investment in research excellence, talent and infrastructure which makes future industry deployment possible, Ireland risks becoming less attractive for company investment in the emerging areas of advanced manufacturing, decarbonisation, the circular economy, quantum computing and advanced therapeutics.

Foreign direct investment

Foreign direct investment has been a key pillar of Irish economic policy since the 1960s and considerable success has been achieved. According to 2021 CSO figures, Industry is dominated by foreign-owned enterprises, producing 89.9% of Gross Value-Added (GCA), and 89.0% of turnover. There were 1,135 foreign-owned multinationals, which represented 5.5% of all Industrial enterprises and accounted for almost half (49.0%) of persons employed[42]. With the impending changes to global corporation taxation, Ireland will have to increasingly focus on other elements of its FDI offering, particularly the quality and skills of the workforce, the extent to which R&D and innovation are embedded in business models, and the energy and physical infrastructure. The IDA postulates that for Ireland to remain successful, it is vital to fast-track the delivery of renewable energy, promote research, development, and innovation, and ensure a competitive offering to international companies. It believes that continued action at speed and scale to address these issues is essential if Ireland is to successfully move to an internationally competitive low carbon, high tech economy. This is essential to maintaining existing levels of investment and to fully realise opportunities in the years ahead. The agency is focused on cross-sectoral opportunities in addition to sector specific growth areas including those areas where advanced materials innovation is highly relevant such as Medical Technologies, Advanced Therapy Medicinal Products (ATMPs:) which spans medical device and pharma sectors, and Semiconductor Chips and Engineering & Industrial Technologies.

41 National Competitiveness and Productivity Council. (2023, June 22). National Competitiveness and Productivity Council Bulletin 23-2 International Innovation Indicators. https://www.competitiveness.ie/publications/2023/bulletin%2023-2%20international%20innovation%20indicators.

42 Multinationals: An Irish perspective business in Ireland 2021 – detailed results - central statistics office. (2024, January 30).

The scientific community will have to play a key role in ensuring the economic model is conducive to sustainable economic growth and development. In their Ireland's Innovation Index 2023[43], KPMG have highlighted the challenges Irish based MNCs face in retaining innovation activity and existing levels of RD&I at the local sites against increasingly competitive international environment noting that the retention of employment in high value R&D jobs can often have an impact on the ability of a company to also retain large numbers of high-skilled manufacturing roles, particularly where R&D is co-located with the manufacturing of the output of the R&D. In the materials sciences, FDI companies such as Intel, Merck, Johnson and Johnson, Boston Scientific, Alcon, Henkel, and Analog Devices have a significant manufacturing and research footprint in Ireland and are actively engaged in collaborative research activities which are rooted in fundamental, early-stage research with the AMBER Centre. Although each of these engagements are unique and driven by the business needs of these individual companies, there are consistent themes underpinning these engagements which define a consistent value proposition, and which are as follows:

- An international reputation for scientific excellence which can be externally benchmarked is the primary consideration when choosing an academic partner.
- Scientific excellence by itself is insufficient, this must be matched by a professional management structure to ensure the engagement and delivery of research projects align with the expectations and requirements of the business environment, facilitating effective collaboration and project execution.
- Access to a talent pipeline is as important to the company as the research engagement itself. Collaborating with academic partners that can provide skilled graduates helps companies access the expertise needed to drive innovation and meet business objectives.
- The ability to demonstrate a mature research and innovation ecosystem which can provide access to internationally leading academic research and an equally high calibre engagement model is a significant advantage to the local entities of FDI companies when competing for increased R&D charters which can define future site strategies.
- The below average public investment in RD&I (as % GNI*) and the underinvestment in research infrastructure is a risk with respect to the continued ability of the system to execute on research programmes and graduate training which is relevant to the company's needs.

Strengthening the Irish-Owned Exporting Sector

A key priority of National Enterprise and innovation policies is to increase productivity and R&D levels within Irish SMEs as a response to the risks associated with our overreliance on multinational corporations and the persistent innovation gap between these sectors. The current Enterprise Ireland (EI)'s strategy Leading in a Changing World 2022-2024[44] has set a target for cumulative client RD&I spend reaching €3.8 billion by 2024 and increasing productivity by 2.5% per annum. In their most recent annual report EI reported an R&D spend by client companies of €1.5 billion in 2022[45] which signals that the cumulative target will be achieved for the industry sector. For the early advanced materials research conducted in SFI centres such as AMBER, SME engagement is predominantly characterised by science-led, venture backed, startup companies. The development costs and relative maturity/market readiness of the technology are the predominant barriers for engagement. The value proposition for the companies that do engage is centred on enhancing their own value proposition to prospective clients though access to scientific expertise and research capability. Access to expertise including internships and SFI research fellow schemes enhance future engagements and an effective way for addressing a company's talent pipeline while increasing the in-house capacity for research and development activities. The Enterprise Ireland funded Technology centre Irish Manufacturing research (IMR) and CIRCULÉIRE, the industry-led circular innovation network, and Gateways the Centre for Research in Engineering Surface Technology (CREST) Gateway, South Eastern Applied Materials (SEAM) and Applied Polymer Technologies with their charter or market-focused strategic R&D projects, with support from research institutions are well positioned to support SME companies in the mid to high TRL research activities.

43 Ireland's Innovation Index 2023. KPMG, IRDG, 14 June 2023, assets.kpmg.com/content/dam/kpmg/ie/pdf/2023/08/ie-irelands-innovation-index-2023-2.pdf Accessed 21 Feb 2024

45 Enterprise Ireland. (2023a, June 16). Annual report & accounts 2022. https://www.enterprise-ireland.com/documents/2022-annual-report-and-accounts-en-54476.pdf

The mechanisms through which companies engage with the system as a whole however are unclear and requires further streamlining. The lack of a formal national structure or incentive for SFI centres and EI centres to cross collaborate in translating materials innovation from the early lab stage to pilot scale and beyond which is a significant gap, with centres often competing with each other for respective metrics than collaborating. Any future national strategy will need to design a flexible mechanism for these different entities to work more cohesively to better serve the needs of our SME sector with respect to early-stage research, applied innovation and skills development.

Quality of Labour Force

The skills and education of the labour force is an essential driver of labour force productivity. he level and relevance of education in the labour force, along with experience, and talent is crucial. Ireland performs comparatively well in talent and skills, with the second highest share (after Japan) of working age population with tertiary education in the OECD. Despite ranking fourth lowest in the OECD in terms of compulsory instruction time spent on STEM subjects at primary level, Ireland leads EU members in terms of STEM graduates per 1,000 of population aged 20-29. However, indicators such as falling numbers of MSc and PhD students and declining funding provision indicates issues at higher levels of education and training. The comparatively low PhD stipend and post-doctoral salary scales relative to Industry and International benchmarks coupled with the high cost of living is an emerging risk making Ireland a less attractive location for researchers to build their careers.

The National Skills Council at SOLAS has highlighted skills shortages in certain sectors[46]. It recognises that while **'provision from the third level education system for science and engineering graduates remains strong, the strong employment growth for these occupations and the demand for the skillsets associated with scientists and engineers (e.g. critical analysis, problem solving) across a range of other occupations (e.g. public administration professionals, teachers, among others), will ensure continued demand and job opportunities or these roles.'**

It suggests that the ongoing transition towards a low carbon economy **'is expected to result in a demand for additional skills amongst scientists (e.g., ecology, environmental, conservation), electrical engineers (e.g., renewable, and high voltage) and technicians (e.g., solar/wind). Future demand for these occupations is anticipated to be strong, with shortages likely to continue.'** In the Summer Skills Bulletin 2023, SOLAS projects that there will be a requirement for 64,000 extra science and engineering professionals between 2021 and 2035 and a requirement for 46,000 science and engineering technicians and associate professionals between 2031 and 2035[47].

Fostering of research talent is enshrined within the IMPACT 2030 document and witnessed by the SFI strategic plan. Within the further and higher education landscape, doctoral training through individual schools, SFI research centres or SFI Centres for Research Training are the focal point for postgraduate researcher training providing students with the skills to prepare them for future careers. In addition to national training strategies, international training schemes can be exploited. This is through collaborative industry programmes or engagement with EU funded programmes such as the Marie Skłodowska-Curie Actions (MSCA).These are dedicated grants to the most promising young researchers from across the world to continue their work in the EU. In the field of materials science, where the timeframe from early-stage science to commercial realisation can span several years, the transition of highly skilled graduates to industry or to academia as independent researchers can be a more near-term tangible measure of return on investment. Taking the AMBER centre as an example 240 of our PhD student and postdoctoral researchers have moved to roles in Industry since 2012, representing 30% of the total cohort. Additionally, 80 researchers have established successful careers in academia. For materials science, investment in research and research talent have a strong co-dependency on an investment on research infrastructure. To continue to attract and train the best students and researchers, maintain a reputation for scientific excellence which is relevant to manufacturing industries the current deficit in availability of up to date, basic research infrastructure which is collocated with the research activity must be addressed.

46 National Skills Bulletin 2022, National Skills Council, SOLAS.

47 Summer Skills Bulletin 2023, Using Cedefop forecasts (2021-2035) to inform future demand for skills in Ireland, SOLAS.

—05 Indicative Areas for Targeted Further Investment

Whilst all areas of materials science from packaging through to semiconductors are critical areas of investment, we choose three areas where investment is critical as exemplars of need.

Climate Change

In Ireland, the Climate Action Plan 2024[48] provided a detailed plan for taking decisive action to achieve a 51 per cent reduction in overall greenhouse gas emissions from 2018 levels by 2030 and setting the country on a path to reach net-zero emissions by no later than 2050, as committed to in the Programme for Government and set out in the Climate Act 2021. Failure to achieve these targets could result in significant fines. The Parliamentary Budget Office[49] warned that 'Ireland's failure to reduce our greenhouse gas emissions will result in hefty fines at EU level, estimated to be €600 million annually from 2021, until targets are reached. Failure to reach 2030 targets may result in fines in excess of €1 billion.' **It is hard to imagine how Ireland will meet its commitments on climate change as well as the circular economy, waste, renewable energy without very significant investment in materials research and innovation.** Further, for Ireland to be competitive for further FDI and provide opportunities for start-up and SME growth, Ireland must be an industrial leader in climate mitigation strategies, renewable energy, sustainable technologies, and climate compliant advanced transport. Key foci for Ireland include generation and storage of renewable energy, electrification of the motor fleet, retrofitting residential and commercial building for low energy use, a circular construction and built environment sector, sustainable agricultural production, air travel and a circular economy across all sectors to minimise resource use and waste.

A recent IDA survey shows that at least 20,000 jobs will be needed in Ireland in the green economy by 2030 and providing a strong eco-centric business proposition is a significant opportunity. A similar opportunity exists in the emerging circular economy with millions of jobs being created around Europe in the same timeframe[50].

Materials innovation is a key element to delivering solutions in all these fields. In the construction sector increased use of renewables (wood, timber), recycling of steel and low carbon cement are examples. Advanced construction materials and technologies are essential and will play an important role in helping the construction sector contribute towards net zero. In air travel, the move to biofuels derived from waste or renewable resources as well as the future development of hydrogen fuels is critical. Renewable energy linked to energy storage and a hydrogen economy are a major opportunity for Ireland but advances in energy storage, carbon capture and hydrogen storage, transport and use are critical elements where off the shelf solutions do not yet exist and reliant on evolution of new materials.

48 Department of the Environment, Climate and Communications; (2021, November 4). CLIMATE ACTION PLAN 2021 Securing Our Future. https://www.gov.ie/en/publication/6223e-climate-action-plan-2021/

49 https://data.oireachtas.ie/ie/oireachtas/parliamentaryBudgetOffice/2019/2019-07-09_the-climate-actionplan-a-review-of-potential-exchequer-implications_en.pdf

50 EU circular economy could create two million jobs by 2030. The Parliament Magazine. (2020, June 29). https://www.theparliamentmagazine.eu/news/article/eu-circular-economy-could-create-two-million-jobs-by-2030

Demographics and Healthcare

The provision of healthcare is becoming an increasingly difficult challenge for the developed world associated with meeting the rapidly increasing demand of an ageing population within finite fiscal resources. In Ireland, analysis from the Irish Fiscal Advisory Council suggests that ageing and the general rise in people's incomes are likely to have played a significant role Ireland is a particularly high spender on outpatient services – daily hospital services excluding overnight or longer-term hospitalisations. The Council's long-term projections suggest that 'public spending on health in Ireland would rise from 8.3 per cent of GNI* in 2019 to 13.2 per cent by 2050.' Further, extensions to Sláintecare will exert considerable pressure on health spending. Issues are exacerbated by Ireland's growing population, reaching 5,281,600 in April 2023 with increasing average age. There were 806,300 people living in Ireland aged 5 and over in April 2023. Those aged 65 and over showed an increase in population share between 2017 and 2023 from 13.6% to 15.3% of the total, a volume increase of 153,900 people. The older segment of the population will increase significantly over the coming decades, and this will place considerable pressure on an already stretched healthcare sector.

Recognizing fiscal resources available will be limited, the priority is to deliver the best possible value for scarce resources and ensuring the most cost-effective healthcare solutions are delivered. **The role of the wider health-tech sector including the digital & connected health areas will see materials innovation in next generation devices and therapies and the increased influence of digitally enabled medical technologies to meet these challenges.** This needs to be fully appreciated by policymakers and funders. A healthcare system where patient outcomes and the patient experience are improved; where there is reduction in the need for hospital stays and lower lengths of stay; and generating greater efficiency in the delivery of health services is the target.

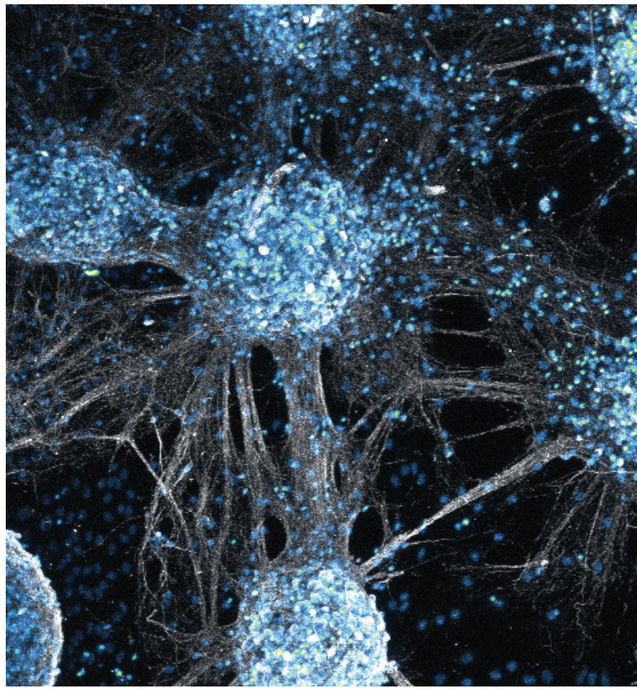
The potential to make a much more profound impact on the delivery of healthcare through well-funded materials and medical technology research is now more significant than ever. As the EU hub for the MedTech sector, Ireland is exceptionally well placed to capitalise on this opportunity.

The Semiconductor Industry

Globally semiconductor sales generate more than 1 trillion US$. Semiconductor chips are becoming ubiquitous with proliferation in everything from automotives through to renewable energy management to wearables and digital health. This is driving significant growth and there is a global impetus to increase capacity with region specific "Chips Strategies" implemented across the US, Japan, China, and Europe. The semiconductor manufacturing process is materials intensive relying on a number of critical raw materials such as silicon, gallium, indium and germanium, complex synthetic materials (photoresists) for patterning and process chemicals including acid, fluorochemical gases and water. It is highly reliant on complex supply chains particular issues regarding supplies of germanium, gallium and rare earths imported from China which are vital to performance. Demand for higher performing semiconductor devices with lower power consumption is creating significant opportunities for materials innovation, in addition the industry has significant problems in meeting sustainability goals. It currently is responsible for more than 5% of global emissions and by 2050 the ICT sector could be responsible for more than 20% of all emissions globally[2].

In Ireland, the semiconductor fabrication sector generates in excess of €3 billion raising wider revenues for the country to more than €15 billion[51]. According to the Irish electronic industry cluster MIDAS, the sector is responsible for over 20,000 jobs and has an annual R&D spend of €450M[14].

A national semiconductor strategy is currently under development and being led by The Department of Enterprise, Trade and Employment to ensure that Ireland can compete for and avail of the opportunities presented by the European Chips Act, and to meet ambitions for the sector. In Ireland, recruitment and training are a pressing issue with the current pipeline of scientists and engineers not meeting demand. **Maintaining a competitive and relevant semiconductor industry in Ireland which meets our national aspirations will require access to materials expertise and talent as well as a vibrant research community which has the credibility to sustain collaborative research partnerships with global semiconductor companies.** The need to provide high quality training on appropriate infrastructure and facilities across continuing personal development, diploma, MSc, and PhD levels is critical. Coupled for the industry to draw on world class research to support developments there is a clear case for significant spend across education, academic and industry-based research.



Credit: Jack Maughan, AMBER Researcher: 'NeuroGraph - Neurons isolated from mouse brains grow on conductive graphene composites in the presence of electrical stimulation for neural interfacing.'

51 Integrated Circuits - Ireland: Statista market forecast. Statista. (n.d.-a). https://www.statista.com/outlook/tmo/semiconductors/integrated-circuits/ireland

Concluding Remarks & Recommendations

The Irish economy faces numerous challenges and opportunities over the coming years. The key challenges include ensuring Ireland remains as conducive as possible to strong national competitiveness; continuing to grow foreign direct investment and indigenous enterprise; maintaining the amount and quality of the labour supply.These challenges are set against the disruptive issues around climate change, biodiversity and coping with the implications of changing demographics especially in relation to healthcare. A critical issue is maintaining Ireland's vibrant export markets against increasingly uncertain global geo-political backdrop and fragile supply chains.

The White Paper on Enterprise 2022-2030 sets out the ambition for Irish-based enterprise to meet these challenges and succeed through competitive advantage, founded on sustainability, innovation, and productivity, delivering rewarding jobs and livelihoods. Our significantly lower rate of R&D spending relative EU and other OECD nations questions our ability to achieve this goal as eflected in our consistent underperformance in IMD, Work Bank and World Economic Forum Global Innovation rankings. The lack of ambition in reaching at least average levels of national research funding is disappointing and may diminish Ireland's ability to retain its reputation and role as a significant innovator and exporter of high-tech products and solutions, to attract FDI and build a significant indigenous technology industry.

On emissions, Ireland ranks well behind the EU average on carbon dioxide equivalent per capita, averaging 11.8 tonnes per head against the EU average of 7.5 tonnes, whilst at an enterprise level just 17% of Irish firms are implementing green management practices, against an EU average of 42%.

This must be coupled to strong warnings from the EPA of Ireland missing its 2030 goal of a 51% reduction in emissions[52] and a deteriorating situation due to recent undercounting of current emissions such that at best we might expect a 25-30% cut in emissions. The slowdown of wind power installations suggest that renewable energy targets will also be missed. The lack of environmental progress is also reflected in Ireland poor record on materials circularity, amongst the lowest worldwide. These issues threaten Ireland's ability to do business an eco-centric world. With EU directives compelling companies to report key sustainability metrics and comply with climate targets, economies that can supply renewable energy, promote circularity, and enable their own sustainability targets will become favoured as business locations.

The importance of materials science in addressing these challenges and driving forward high value-added economic growth and development should not be ignored. Ireland's economic model increasingly relies on materials so it is essential that an ecosystem where the country is investing in materials science must be fostered. On the basis of this we propose the following must be actioned to maintain Ireland at the 'top-table' of materials research, innovation and application across its critical manufacturing centres.

52 O'Doherty, C. (2024, February 29). Emissions "miscount" means carbon cuts must be even higher. Irish Independent. https://www.independent.ie/irish-news/emissions-miscount-means-carbon-cuts-must-be-even-higher/a1001167754.html

— **A national stakeholder group should be created to inform policy and funding for materials science and act as a national materials forum.** This should consist of industrialists, academics, and relevant Government agencies (across higher education, enterprise and other departments and agencies covering environment, farming etc.) to identify priorities, needs and a national strategy. This group should facilitate a more streamlined system for collaboration, knowledge exchange, technology transfer and translation.

— **Funding for materials science should remain a national priority.** The SFI and other centres in this area, must be maintained. AMBER has made a disruptive contribution to materials science nationally and internationally and its leading role most be sustained and grown. There is an opportunity to build a truly world-leading centre carrying out world-class research and innovation based around the AMBER centre. This may be co-funded by SFI, the IDA and Enterprise Ireland and the merger between smaller materials-based centres should be considered.

— **As an urgent priority Ireland should increase core funding for science to meet EU and OECD expectations.** This will require a rapid doubling of the science and engineering research budget.

— **Ring-fenced funding should be delivered aimed at key areas associated with materials which align with national priorities.** This includes funding for materials for renewable energy and hydrogen, sustainable materials-based technologies, materials for healthcare applications including digital and health, sourcing of renewable materials, developing artificial intelligence for discovery and application as well as quantum computing.

— **The national infrastructure supporting materials science research and innovation requires investment to be consistent with other international research competitors.** There should be an immediate inventory of facilities currently available and identification of what is needed to bring our current infrastructure to the required level. Funding should then be provided for new infrastructure investment and any consolidation needed. This may be an opportunity for the funding and development of a national materials characterisation should be considered.

— **There should be an associated materials training scheme developed funded from the National Training fund.** This should span CPD, diploma, MSc, and PhD schemes. Targeted MSc and PhD training funding should be developed at the 3rd level sector with appropriate industry co-support and internships. Skills training should be focused on critical gaps such as sustainability where there are recognised national shortages identified. A focus of training should be made in light of the emerging EU Academies in renewable energy and materials science.

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